TC-M-Series Temperature Controllers

V1.08

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1 Introduction

Our TC-M Lite series of Temperature Controllers are designed for use with thermoelectric coolers also known as TEC's or Peltier devices. These offer precise temperature control from –200 ºC to 100ºC at up to 0.05ºC stability. Our controller can be setup or controlled from a PC via USB allowing access to output limits, PID terms, deviation alarms and operating modes.

Typical uses for any precise temperature control system include laser diodes, infrared detection, high gain amplifiers and cold plate assemblies.

The TC-M Lite series temperature controller is suitable for controlling single and multiple TEC arrays. It provides a pulse width modulated output which effective provides a continuously variable output for cooling and heating.

The TC-M Lite is programmable from a PC allowing configuration and tuning to meet system requirements. This configuration data is stored internally allowing standalone operation once programmed. The interface and command set allow the unit to be controlled remotely; in particular this allows changing of the set point and alarm temperature settings.

2 Controller Functions

The controller has the following functional parts –

2.1 Sensor measurement

The input stage provides measurement for resistive and voltage output sensors. These are measured by a sophisticated delta-sigma ADC which gives excellent accuracy and noise suppression.

TC-M Lite units can be supplied that support the following sensors:

- PT100/PT000 Resistance Temperature Detectors (RTD)s
- Voltage Sensors (LM35, LM50, LM51, LM60, LM61)
- NTC Thermistors

Suitable for PT100 sensors - 100 R accuracy 0.05 ºC: Covers –200ºC to +400ºC range.

2.2 CPU

This provides all the intelligent control, measuring the input values and calculating the output required for the control type. It also provides storage for the configuration parameters.

2.3 Output driver

This provides a bi-directional variable output drive to the TEC element(s). The output switches at the preset repetition rate and adjusting for output value by setting the PWM duty cycle.

2.4 Communications

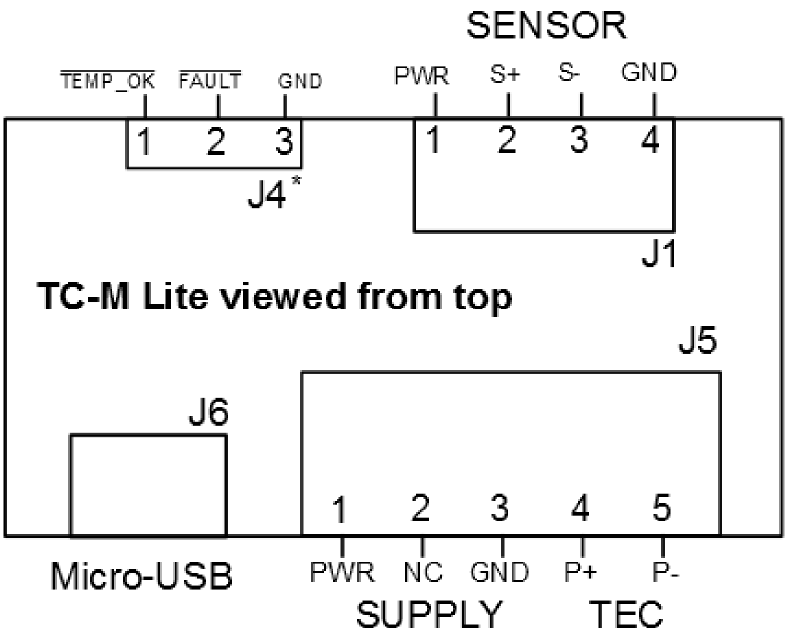
A virtual com port is provided via a USB connection. The latest driver for the onboard FTDI USB controller can be found at http://www.ftdichip.com/Drivers/VCP.htm.

2.5 TEC Output

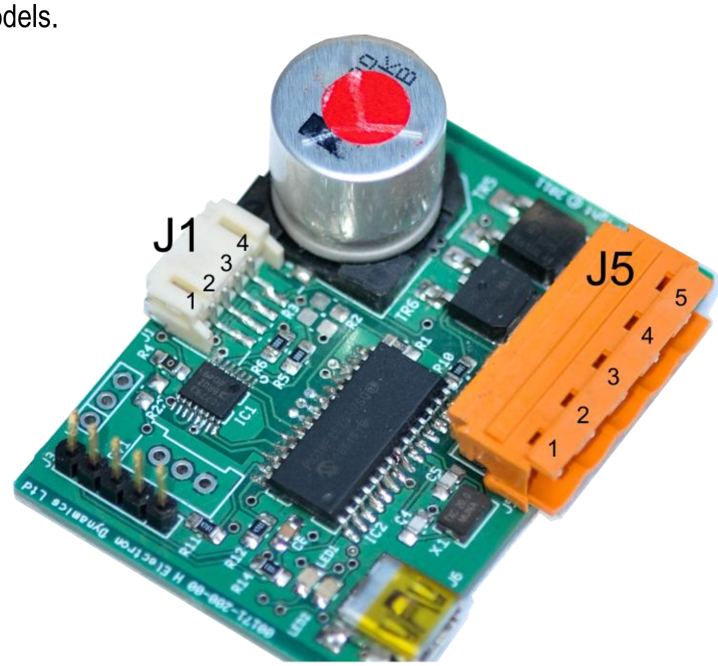
The maximum TC-M Lite output voltage to the TEC is that of the supplied TC-M Lite input voltage. It should be ensured that the input voltage supplied to the TC-M Lite is less than the maximum specified input voltage for the TEC used. A safety margin of 20% is advised.

3 Connections

The following section details the connections necessary for the TC-M Lite. The figures below show the pin-out of the TC-M Lite.



* N/A in cased models.



3.1 Temperature Sensors

3.1.1 PT100 and PT1000 Measurements

Connect PT100 sensor to J1 on pins 2 and 3 with screen to pin 4.

3.1.2 Voltage sensor measurements

For voltage outputs sensors, LM35, LM50, LM51, LM60, LM61 configure the following links on the TC-M Lite PCB.

Connect sensor to J1, Sensor + to pin 2, sensor - to pin 3 and sensor GND to pin 4. In this configuration LM35 operates down to zero degrees C but not below.

3.1.3 NTC thermistors

Connect thermistor to J1 between pins 2 and pins 3, connect screen to pin 4 if used.

For best operation use 10K types these have a better range in this circuit. Other values can be accommodated if required. Consult Electron Dynamics for possibilities.

3.1.4 Other temperature sensors

For requirements outside of the supported temperature sensors please consult Electron Dynamics for advice.

3.2 TEC connection

Connect to J5 pins 4 and 5 noting polarity, actual drive polarity can be configured by software.

3.3 Power connection

Input voltage should be applied between J5 pin 1 and Pin 3. Pin 2 is reserved for future use and should be left unconnected.

3.4 Alarm output

This is provided from J4, this is active when low.

3.5 USB

This is provided from J5. Note this operates as a virtual COM port

3.6 Status Output

The TC-M Lite series temperature controller has two outputs that show the status of the controller. The signals on J4 are available on the non-cased TC-M Lite version only.

TEMP OK (Pin 1)	HIGH – Temperature ok in relation to set point and user defined settings
TEMP OK (Pin 1)	LOW – Temperature out of range
Fault (Pin 2)	HIGH – Temperature controller working correctly
Fault (Pin 2)	LOW – Indicates an alarm or inhibit (External or Internal)

4 Thermal Issues

4.1 Thermal Assembly

This is a critical component in the system design; typically there are 2 potential pitfalls –

- the heatsink is not large enough
- the thermal conduction between components is poor

It is worth reading the extensive material available from the peltier / TEC manufacturers to find out the requirements for this. See www.marlow.com and www.lairdtech.com

4.1.1 Heat sink size

The size of this should be chosen using the manufacturer's calculations; it will need to be large enough to radiate the heat required. Typically they have a large heat capacity but often are more limited in their capability to dissipate the heat. This is often seen when operating under temperature control there is a continuous rise in heatsink temperature or rise in drive current. It should be noted that there is a point in where the system can go into thermal runaway, as the heatsink is unable to dissipate the heat properly and the temperature of the sample and heatsink will continuously climb.
Heatsink dissipation capacity should be chosen to be larger than necessary. Using a fan on the heatsink can decrease the thermal resistance to air by as much as 3 times and will give a significant improvement to thermal dissipation.

4.1.2 Thermal Conduction

It is important to ensure that there is a good thermal path between the Sample, TEC and heatsink. Not only does this provide good heat removal / dissipation but will improve the temperature stability.
Also important is that the mating surfaces are reasonably flat and that just enough heatsink compound is used to make the thermal connection. A misconception is that more compounds will be better, however excessive thermal compound reduces the thermal connection, compromising the temperature stability.

4.2 Peltier Size

This should be calculated from the manufacturer's selection. It is important that the TEC is not driven beyond its maximum, the device will certainly be damaged if the maximum current is exceeded. Due to the nature of the peltier device as the drive is increased above between 60 and 80% of maximum it becomes progressively less efficient and in this situation will tend to just provide more local heating that heat pumping. This can possibly lead to thermal runaway if the limit is not set. We feel that there is little point in working the devices in their inefficient region and recommend that device are run at a maximum of 80% of maximum drive.

4.3 Drive Limit

The TC-M Lite series allows the allocation of maximum TEC drive limits. 100% represents the voltage of the TC-M Lite input supply. For example, to reduce a 12V supply to a maximum drive of 6V limits of +50% and -50% would be used. If the supply was instead 9V and 6V drive limits were required, +67% and -67% would be applied.

4.4 Important stability issues

Facilitate faster settling time and response

- by reducing thermal mass of sample
- reduce distance between TEC and item being cooled

Improve accuracy by locating sensor as near to cooled device as possible.

Reduce thermal load by reducing thermal feedback from heatsink to sample by using thermal insulation.

5 Temperature Controlling

5.1 Off mode

This is purely a mode in which under temperature control the output drive is off. This is intended for diagnostics or to ensure a failsafe condition.

5.2 On/Off control

This mode of temperature control is the most basic, it benefits from being relatively easy to set up. Simply specify the set-point, and dead band. Whilst this method may be sufficient for some applications there are some problems with this approach; due to full on / full off nature of the output, the temperature stability is relatively poor. A second problem is that TEC is cycled fully heating and the fully cooling, this may cause reliability issues with the TEC itself.

5.3 PID Control

PID control comprises of three elements Proportional, Integral and Derivative and is well established as being the foremost temperature control method.

The Proportional term provides a variable output which as the temperature deviates further from the set point then the output drive increases until the maximum is reached. The response of this is defined by the value of the P term.

Output = (set-point - actual temperature) * proportional term

The main issue with a purely Proportional response is that there is always a steady-state temperature error. This is due to the fact that in order to provide an output then there needs to be a temperature error.

Using an integral term overcomes the problem of steady state errors, practically it accumulates any error and applies this to the output drive to compensate, Increasing or decreasing it accordingly. Though there are direct benefits in temperature accuracy there is some sacrifice in system stability particularly as the integral effect is increased.

The derivative term provides an output proportion which varies with the rate of the input error or output. This provides a faster response to temperature variations and also provides a stability balancing effect to the integral term. Please note that for best stability there must be a fixed ratio between the I term and the D term normally 4 to 1.

Due to the inherently large gain of the derivative at high frequencies at filter, the derivative TC is provided to attenuated high frequency noise.

5.4 Tuning the PID parameters

The PID parameters can be tuned using various methods, There are many methods of tuning the PID parameters required, some of these also allow you to tailor the response in certain ways. Three popular methods are

Relay feedback – closed loop
Ziegler - Nichols open loop – step response
Ziegler – Nichols closed loop – ultimate gain method

The basic methods are mentioned below however extensive materials are available for detailed explanation.

5.5 Temperature test mode

Temperature test mode introduces the option of having a series of set-points, according to which the control loops through after specified intervals characterized for each set-point. Along with that there exists a rate control. Being associated with every set point, this control defines the rate at which the next set point should be approached after the end of intended time-interval. A maximum of five different set points could be used at this mode.

5.6 Relay Feedback – Autotuning

The TC-M features an auto tuning function as standard using the relay feedback method, this makes this tuning the TC-M lite very easy. The user is able to select the set-point around which the auto tuning should occur and how long for the unit to make measurements. The unit then sets up the relay feedback conditions under which oscillation occurs, these peaks are analysed and from these the PID parameters are calculated. The test aborts at the end and uses the new PID parameters for temperature control.

5.7 Ziegler - Nichols open loop – step response

This is open loop so there is no the control function is off, it involves making a step change at the output The input / thermal response should be noted, then using graphical means should be analysed, to give the initial process dead time and the process time constant. From these the respective terms can be calculated -

Td is Process time constant t is pseudo dead time and Kp the process gain

From this the PID terms are calculated

P term is 1.2 (t/ (Td * Kp)) I term is Td / 0.5 and D term is Td * 0.5

5.8 Ziegler - Nichols closed loop – ultimate gain method

This is a closed loop so the control function in on. With the P term set low and the I term and D term off. Monitoring the temperature the gain or P term is increased until there is sustained and continuous oscillation of the temperature. The Gain (P term) required and the period of the oscillation should be noted. From these the PID terms can be calculated.

Where

Gu is the gain and Tu is the period

From this the PID terms can be calculated
Where

P term = 0.6 Gu I term = 0.5* Tu D term = 0.125 Tu

6 Graphical User Interface

The TC-M Lite series Temperature Controller can be operated via *Graphical User Interfaces,* one written in Java and the other in C++. They are very similar with minor differences.

The GUI will be broken down into eight functional categories, each will be explained in the remainder of this section of the manual:

I. Pull Down Menus

II. Control

III. Set Point

IV. Sensor

V. Output

VI. Alarms

VII. Report

6.1 Pull Down Menus

6.1.1 File Menu

Save as defaults allows the user to save a copy of the current GUI set up, which can be loaded using the load defaults command.

The exit command closes the GUI.

6.1.2 Port

The desired communication port can be chosen and the TCM Series Temperature Controller can be connected or disconnected. Please note port needs to be selected and opened at the outset in order to communicate with the controller.

6.1.3 Help

Displays help information.

6.2 Control

6.2.1 Type

The control algorithm can be single or a combination of *Proportional, Integral, Derivative* terms. The list box allows the user to define the controller terms required.

The available options are;

0. None
1. On/Off
2. Proportional
3. Proportional and Integral
4. Proportional, Integral and Derivative

User defined values can manually be entered here for the controller to operate from.

6.2.2 None

This is a default off mode for diagnostic or fail safe purposes.

6.2.3 On/Off

With On /off control the output drive is only fully on, heating or cooling or off.
Its response is –

Temperature > set-point + dead-band   Fully Cooling
Temperature < set-point - dead-band   Fully Heating
Temperature <set-point +dead-band and >set-point – dead-band output off

6.2.4 Proportional

With proportional action, the controller output is proportional to the temperature error from the setpoint. The proportional terms sets the gain for this where

Output = (set-point - actual temperature) * proportional term

6.2.5 Integral

With integral action, the controller output is proportional to the amount of time the error is present. Integral action eliminates offset. The integral term is a time unit in seconds. NB for larger effects of integration reduce the integral time, also for operation without integral, integral time can be set to a large number e.g. 1,000,000.

6.2.6 Derivative

With derivative action, the controller output is proportional to the rate of change of the measurement or error. The controller output is calculated by the rate of change of the measurement with time, in seconds. Increasing the derivative value will result in an increased derivative action. See also Derivative Filter.

6.2.7 Derivative Filter

The derivative filter is a low pass filter function on the derivative value. This allows the filtration of noise components which are a problem with a pure derivative function.

The filter value should be set to between 0 and 1.

6.2.8 Dead band

For use with On/Off control the dead band specifies the temperature range around the set point where the output is zero.

6.2.9 Power Up State

This sets the temperature control state from power up, where this can be set as On or Off or where Last is selected it sets its last setting prior to power off.

6.3 Set point

6.3.1 Method

The temperature set point can be set via the PC or by altering the pot on the TCM series Temperature controller hardware.

For setting via the PC select the PC radio button and enter the set point value into the edit box directly following the radio button.

6.3.2 Pot Range

This sets the temperature range that the pot gives values for.

6.3.3 Pot Offset

This sets the minimum temperature point on the pot.

6.3.4 PC Set Point

This allows the set point to be fixed via the GUI

6.3.5 Control

The control radio button if checked inhibits the temperature control.

6.3.6 Output

The output edit box allows a fixed output to be set. To use this control should be disabled otherwise any setting made will be over ridden by the control. Range 0 to +/- 100%

6.4 Sensor

6.4.1 Type

The supported sensor types are selectable from the list box; refer to the specification section 8.6 in this manual for supported temperature sensors.

6.4.2 X2, X, C Coefficients

These are quadratic coefficients than can be input to convert the sensor voltage measured into a temperature. This can be used for other sensors so that these can calibrated.

Where temperature = (v * v * X2) + (v * X) + C

v is measured sensor voltage and temperature is calculated temperature

The C term allows the user to adjust / shift the temperature to compensate for variations in sensor accuracy. It can be seen that this value simply added to the temperature value. So if your sensor was 1 degree out then make C = 1.
Also provided is buttons to decrease / increase this value in 1 degree steps.

For NTC thermistors different parameters are required

6.4.3 NTC thermistors

For NTC thermistors different parameters are required .

Beta	as specified for thermistor type
Resistance at 25ºC	
C coefficient	degree offset
Rl	drive resistance on TCM 22000 as standard

6.4.4 Units

The temperature can be displayed in degrees Centigrade, Kelvin or Fahrenheit.

6.5 Output

6.5.1 Polarity

This sets the polarity of the output drive,

6.5.2 Minimum

Sets the minimum value limit of the output. Range 0 to +/- 1000

6.5.3 Maximum

Sets the maximum value limit of the output. Range 0 to +/- 1000

6.5.4 Frequency

Sets the PWM repetition frequency of the output drive. Range 20 to 1000 Hz

6.6 Alarms

6.6.1 Minimum Alarm

Sets the temperature below which the alarm is activated. Select via check box to enable.

6.6.2 Maximum Alarm

Sets the temperature above which the alarm is activated. Select via check box to enable.

6.6.3 Minimum OK Temperature

Sets the lower temperature difference point from the set point for temperature OK.

6.6.4 Maximum Temperature

Sets the higher temperature difference point from the set point for temperature OK.

6.6.5 Operational temperature max (Only available on certain GUI)

Sets the temperature maximum, above which the drive output is disabled.

6.6.6 Maximum Temperature (Only available on certain GUI)

Sets the temperature minimum, below which the drive output is disabled..

6.7 Report

6.7.1 Set point

Displays the set point, can be used to ensure the controller has accepted the set point entered in the control category; refer to section 5.3.

6.7.2 Temperature

Displays the measured temperature, the measured temperature units can be Celsius, Fahrenheit or Kelvin and can be selected in the sensors category; refer to section 5.4.3

6.7.3 Control

Displays the condition of the output drive either On or Off.

6.7.4 Output

Displays the output value is set to. Range 0 to +/- 1000

6.7.5 Alarms

Displays whether an alarm is active.

6.7.6 Faults

Displays any fault codes.

6.7.7 Temperature OK

Displays if the temperature is in the ok range

6.8 Reading and Setting Parameters

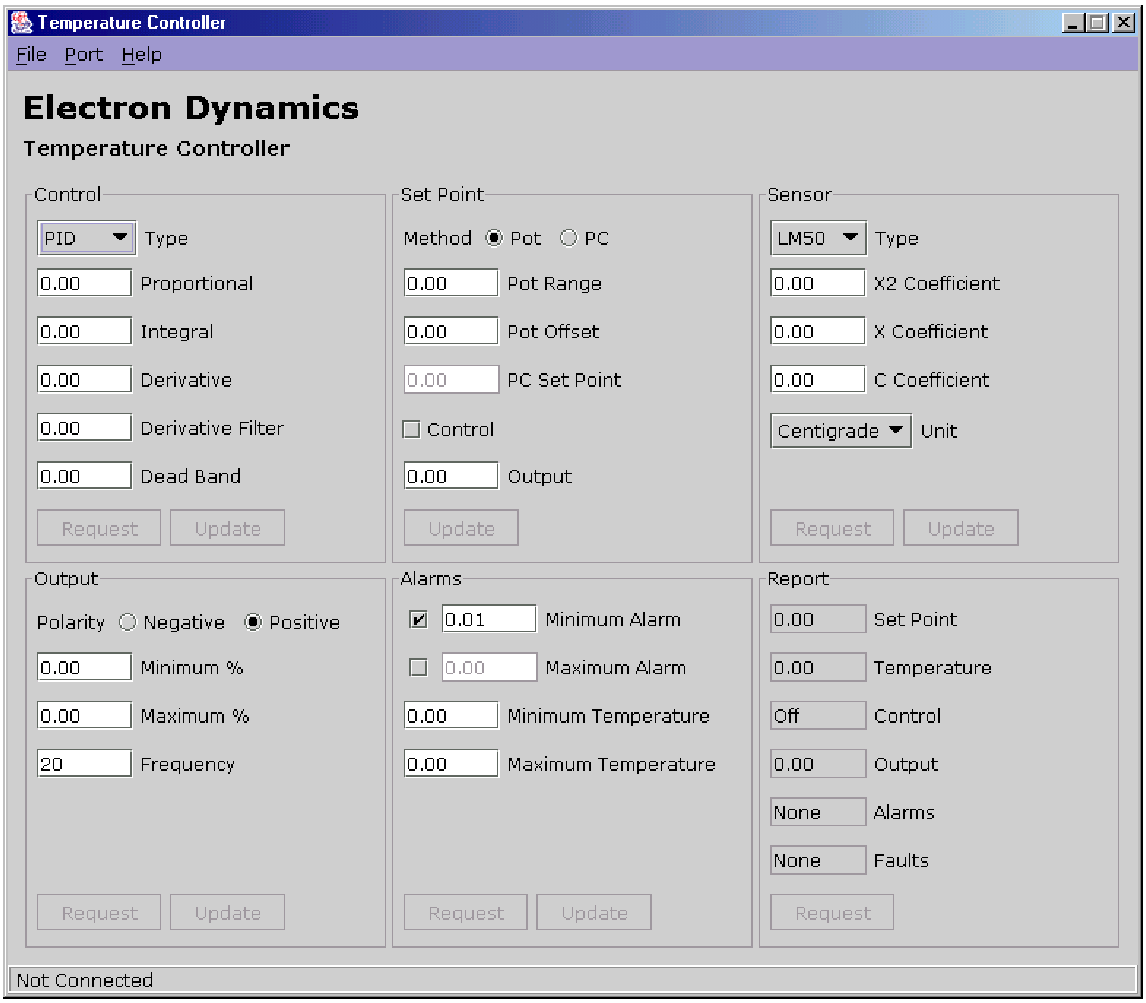
6.8.1 Read Button

The read button will load the respective GUI category with the current condition of the TC-M Lite Series Temperature Controller

6.8.2 Write Button

The write button will load the TC-M Lite Series Temperature Controller with the current conditions entered in to the GUIs category.

6.9 Figure TC-M series Temperature Controller GUI (Java)



6.10 C++ GUI

There are minor differences with the Java GUI as below.

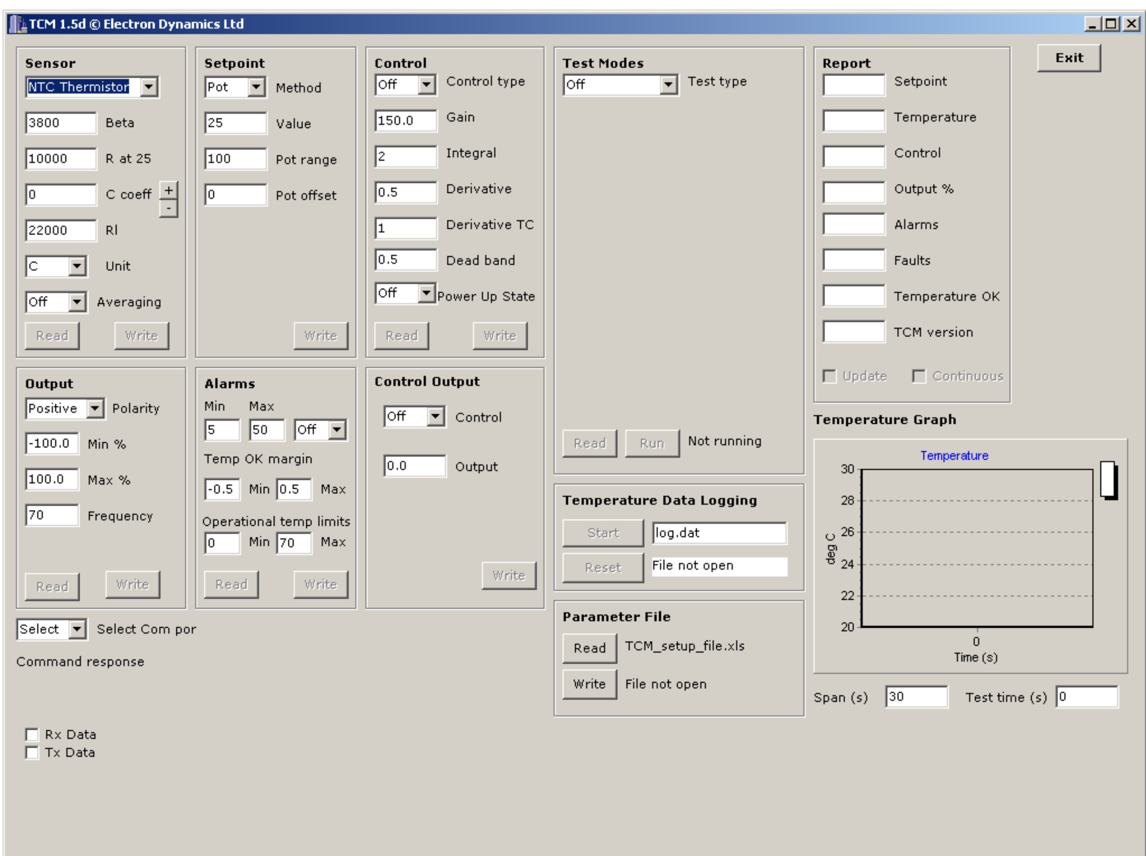
6.10.1 Additional features

The C++ GUI has feature for test mode, temperature cycling and temperature ramping, also included is an auto-tuning algorithm for setting up the PID terms automatically.

6.10.2 Data Logging

This function enables / disables a continuous stream of temperature and output information from the TCM controller. This is stored in a log file for compatible with excel for analysis. This allows the user to measure response graphs for tuning and stability analysis.

6.10.3 C++ GUI



7 Communication Protocol

Please see the commands file on the resources CD-ROM.

8 Specification TC-M Series

8.1 Supply

5v to 28v DC

8.2 Output

0 to 5A (TC-M Lite 5A),

0 to 10A (TC-M Lite 10A),

Bi-directional heating and cooling

Variable output – 0 to +/- 100% 0.1% resolution

PWM rate variable 20Hz to 1000Hz

8.3 Control

From PC via USB

Programmable PID terms

Will operate as P, PI, PID or On/Off with Hysteresis

Resolution 0.05ºC

Max stability 0.05ºC depending on thermodynamics /setup.

8.4 Set point

Set either by pot, or by PC

8.5 Alarm

PC configurable TTL output, active low

High temp. Low temp or out of band

8.6 Sensor

Voltage, PT100, PT1000, LM35, LM50, LM60, LM61, NTC Thermistor, OTHER

Other versions can be calibrated using the quadratic coefficients

8.7 Measurement Accuracy

PT100 0.05ºC or better

LM35 etc. 0.05ºC or better

8.8 User

Windows control software allows access to all parameters

Can be controlled within a process environment

8.9 Format

PCB assembly or Module

9 Sources of Information

For further information on the operation of temperature control peltier units -

http://www.peltier-info.com	- TEC information site
http://www.marlow.com	-TEC manufacturer
http://www.jashaw.com/pid/	- Control E book
http://www.jashaw.com/pid/tutorial/pid6.html	- PID tuning lecture notes
http://lorien.ncl.ac.uk/ming/pid/PID.pdf	- PID notes